VIRGIN GALACTIC: A NEW PLATFORM FOR RESEARCH

Summary Brief for Investigators

INTRODUCTION

Virgin Galactic (VG) is a private company founded to create greater access to spaceflight than ever before. Its aim is to advance spaceflight by operating vehicles which set new standards for spaceflight safety, frequency, flexibility and cost.

The design of the VG spaceflight system and its operations have been built to be flexible in payload and mission profile. As such, the VG program is extremely well suited to the execution of both human-tended and autonomous experiments that support NASA's science, education and technology research goals.
The VG spaceflight system consists of a purpose built carrier aircraft, WhiteKnightTwo (WK2) and an air-launched, reusable suborbital spacecraft, SpaceShipTwo (SS2)

A New Research Platform

The VG suborbital service is well-suited to scientific research, education/ public outreach, and engineering test processes. Such research could include atmospheric science, meteorological science, life or other science associated with macro and microgravity, astronomy, heliophysics, and earth and planetary science. Other applications could include a cost effective means for testing and verification of equipment for orbital and exploration programs, as well as practical training on such equipment in microgravity

Equipment has often been spaceflight-rated using parabolic flight, sounding rockets or piggyback missions. Mission piggy-back can be expensive and availability is poor due to infrequent flight. Airborne parabolic flight is limited in microgravity time. VG's suborbital spaceflights will provide a cost-competitive alternative to sounding rockets with the addition of a human interface environment and a longer window in microgravity for useful training of personnel on specialized equipment or mission scenarios.

Figure 1: The Virgin Galactic spaceflight system: SpaceShipTwo being carried by WhiteKnightTwo

VG will be able to offer researchers several services:

- **Researchers will be able to tend and optimize their experiments in space by mounting them inside the SS2 flight cabin.** SS2's large volume, substantial payload capacity, and multiple windows make the cabin well-suited to a wide variety of research applications.
- **Alternatively researchers will be able to request the management of experiments by VG staff** or provide autonomous experiment set ups.
- **Researchers will be able to mount experiments in the interior, pressurized cabin of the SS2 and/or in unpressurized bays of the SS2 for research requiring direct access to the space environment.** Such experiments can for example, take atmospheric samples and allow exposure to the external spaceflight environment
- **WK2 will offer an excellent proving and training environment for SS2's cabin, as well as an excellent high-altitude research platform in itself.** By design, WK2's cabin is virtually identical to that of SS2, and WK2 is capable of flying zero G parabolas

The SS2/WK2 system offers the following positive characteristics as a platform for science research:

1. The system's characteristics enable rapid vehicle turnaround and high flight rates, which can support series missions in quick succession, even back to back at a pricing point that represents high value compared to the cost and restrictions of current options.
2. The operational flight frequency anticipated offers very short lead time to actual flight and also offers flexibility in scheduling. In other words, the launch window can be tailored to the individual researcher and/or the experiment.
3. The system's characteristics and short lead time to flight also enable 'science of opportunity', such as the study of meteor showers, supernovae and specific atmospheric and astrophysical conditions and events.
4. Services provided via the SS2 / WK2 system offer an order of magnitude more microgravity time than parabolic flights and with order of magnitude lower microgravity disturbances as well.
5. WK2 is capable of parabolic flight and flight sustaining high g levels for researcher training and experiment test (subject to regulatory approval).
6. As the WK2 and SS2 cabins are very similar, equipment training or mission planning can be carried out in the WK2 prior to an SS2 flight.
7. The high-altitude, large capacity and anticipated frequent flight of the WK2 system provides an attractive research platform on its own.
8. All data and equipment is recoverable from VG flights, in most cases immediately following return from flight
9. SS2 has the ability to maneuver in space and accurately point through its RCS system during its parabolic exo-atmospheric trajectory.
10. Down range flight trajectories may become an option in the future and would support extended time at specific altitudes of interest.
11. Operations are planned to take place from Spaceport America in New Mexico, but subject to regulatory and logistical considerations could also use multiple launch sites in the United States.
12. The system is designed to operate with minimal specialist infrastructure and require standard airport type facilities, enabling the potential for the spaceflight system to come to the researcher. WK2 is capable of ferrying SS2 coast to coast within the USA for this purpose.

Overview of Company and Leadership Position

The new industry of entrepreneurial spaceflight offers exciting new opportunities to researchers. At the time of this writing, VG maintains the following distinctions:

- VG is the only company that is building spaceflight vehicles based on a prototype that has already flown to space successfully. SpaceShipOne (SS1) was the world's first privately funded and built manned spaceship that flew to space and back three times during in 2004, thus winning the $10m Ansari X Prize.. The new spaceflight system, replicates the basic design features of SS1 system, consisting of a carrier aircraft (WK2) and an air-launched spacecraft (SS2).
- Construction of the prototype vehicles for VG's commercial operations is substantially complete. The spaceflight system is being proved via a prototype testing phase. At the time of this submission, the prototype WhiteKnightTwo vehicle has undergone extensive flight testing over the past year, with over 60 flying hours. The prototype SS2 vehicle is also complete and is expected to enter flight testing early this year.

- SS2 is the first commercial suborbital spaceflight vehicle to begin spaceflight testing and expected to be the first in commercial operation once adequately proven.
- SS2 vehicle has generous payload capacity and large cabin supporting a diverse payload capacity, enabling freedom of movement without restraints for scientists during microgravity, with seating for six passengers and/or payload fixtures and two pilots.
- VG's plans are centred on achieving significantly higher levels of safety than any previous spaceflight system.
    - Safety case built on core characteristics of system: air launch, glide to land, lightweight, strong and fatigue resistant composite construction, and patented feathered re-entry system
    - Leveraging extensive expertise of the Virgin Group: adopting and refining the safety ethos, organizational structure and practices of the Virgin Group's global airlines such as Virgin Atlantic and Virgin America, train services and customer and tourist services around the world
    - Implementation of a comprehensive human training centrifuge program: this program, pioneered by VG has successfully proven the accessibility of spaceflight to a wide diversity of individuals and is providing essential information for VG to implement a medical program which will benefit the safety of individuals on VG sub-orbital spaceflights and de-risk the commercial venture.
- VG is has been wholly funded to date by Sir Richard Branson's Virgin Group, a large branded venture capital organisation,. This has provided a solid funding stream for the project. Subject to applicable U.S. regulatory approval the Virgin Group expects to receive an additional equity investment from Abu Dhabi's Aabar Investments PJSC. Aabar will take a 32% stake in VG for an investment of $280M. The deal, once closed, will secure funding for the remainder of the development program through to the start of commercial operations. The investment announcement is significant not only for the additional certainty it brings to the funding stream but also as a clear vote of confidence in the commercial potential of VG's business. Its approach and its technology.
- VG is a more developed business than any other potential suborbital spaceflight provider, with over 300 reserved tourism customers, representing more than $43 million of deposits to date, and an additional 85,000 expressions of interest including multiple expressions of interest from the science and government communities in the United States. VG currently has the best current prospects for continued financial viability.
- With its partnership with Scaled Composites and its ownership of The Spaceship Company (TSC) and the Virgin Galactic spaceline operating business, VG has a role in the development of the spacecraft and will ultimately act as the manufacturer and operator of the business. This enables VG to entertain expressions of scientific interest across all lease, purchase and service provision options.
- The dual platform, air-launch design of the VG spaceflight system enables more opportunities for science, research and education, as well as testing and training opportunities through use of WK2 prior to spaceflight.

SCIENTIST BRIEF

General flight profile information

VG uses the air-launch system architecture demonstrated successfully by Scaled Composites during the SS2 / WhiteKnight One program. In this architecture, a purpose-built carrier aircraft powered by commercial jet engines carries the spaceflight vehicle to launch altitude (approximately 45,000ft). The spaceflight vehicle is air-launched from the carrier vehicle and fires its rocket motor, executing a turn for a steep climb. The SS2's trajectory follows a typical ballistic arc and deploys its unique and patented 'feathered' configuration for re-entry. Following re-entry and descent into atmosphere, the spaceflight vehicle de-feathers and glides to a horizontal landing at its launch base. See Figure 2 below for a depictive overview of the flight profile.

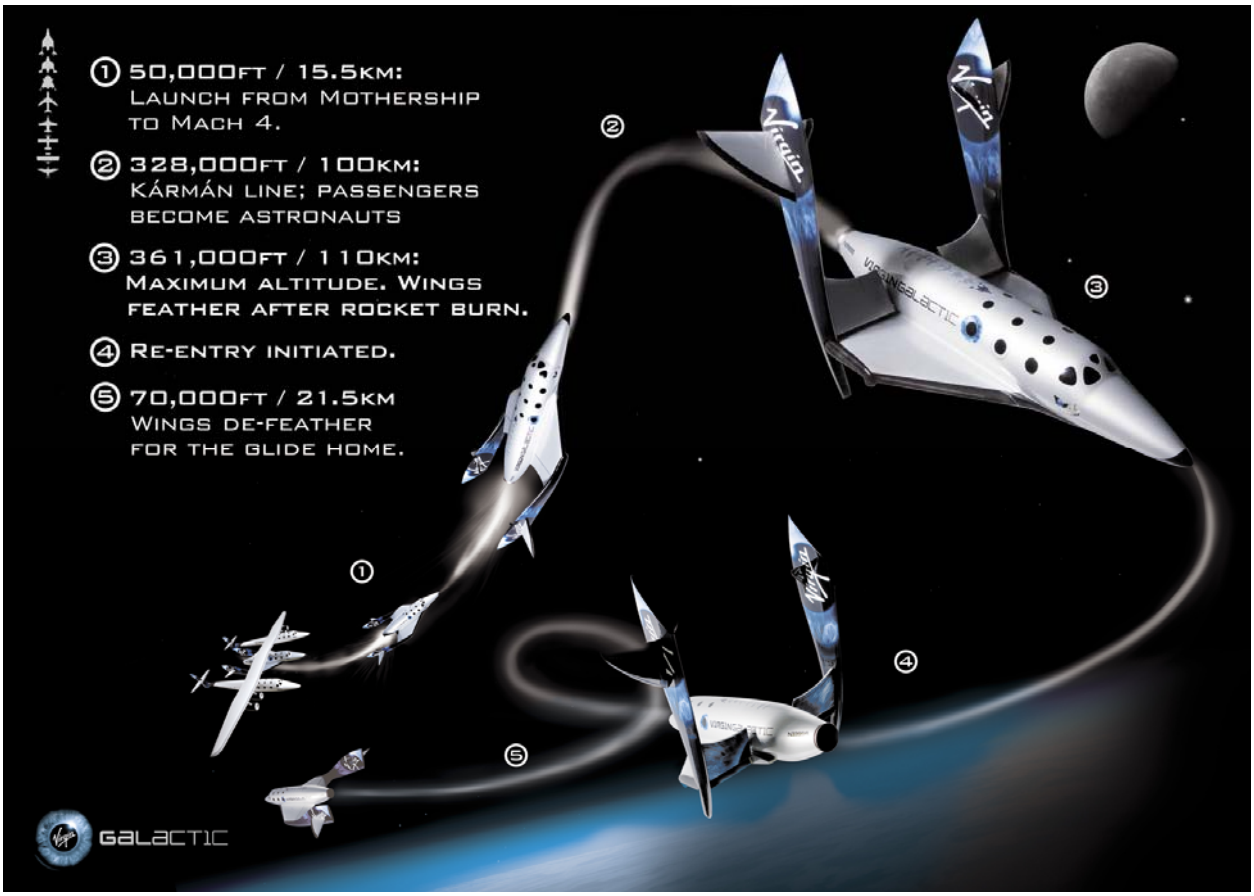

Figure 2: Nominal Virgin Galactic mission profile

Trajectory description

The climb up to altitude for the combined spaceflight system is expected to take around an hour. After being dropped by WK2 at a nominal altitude of 45,000 ft, SS2's rocket motor ignites and the vehicle pitches up into a steep climb. Powered flight lasts ~ 70 seconds, before the motor shuts down. SS2's trajectory then follows a typical ballistic arc.

Passengers and payload will experience up to 4 G on launch and a peak of 6 G on re-entry. Launch g's reach a maximum of 4 g's in both gx and gz vectors during boost, though gz vectors are of short duration during the pull up maneuver only. Any passengers are seated during boost, taking the boost g-forces through the chest for the long duration component. Re-entry G's are taken in a supine position for passengers, directing the g through the chest (gx axis relative to the passenger), which is more tolerable. Re-entry lasts approximately 70 seconds before the SS2 re-configures to a glider for approach and landing.

There are two opportunities to do atmospheric science, on ascent and descent of approximately 20 seconds each, and one opportunity of approximately 4 minutes to undertake microgravity science.

A nominal SS2 payload (including passengers and crew) is expected to result in an apogee of 110 km (360,000 ft) using the flight profile described above.

VG expects to fly the described nominal mission profile to 110km with high accuracy and repeatability. Accuracy and repeatability, as well as safety are critical operational characteristics for the VG tourism and science markets. However, VG also anticipates the ability to be able to accurately target a specific altitude and hence microgravity times, within the design range of the spaceflight system, on demand. This design range (to be confirmed during flight testing) is between 70 – 130km.

Payload standardization

VG will have a baseline seat for tourism operations and baseline rack for individual (direct passenger replacement) payloads. Details of the payload rack will be provided when available, however VG is willing to work with NASA and/or other payload customers to accommodate different types of payloads and racks.

Launch/landing sites

Commercial operations are baselined for New Mexico's Spaceport America, being constructed adjacent to the White Sands Missile Range (see Figure 3). Test flights of the system are expected to be performed at the Mojave Air and Space Port. The operational and research advantages of Spaceport America are listed below.

New Mexico's Spaceport America, being constructed adjacent to the White Sands Missile Range (WSMR), will be Virgin Galactic's primary base of commercial operations (see Figure 3 below).

Spaceport America has many advantages for science-focused flights:

1. Clear surrounding airspace due to remote location and proximity to White Sands Missile Range (WSMR).
2. Excellent weather conditions conducive to high flight frequency and rapid turnarounds.
3. Distance from major urban areas positive for certain climate and astronomy work, due to low urban particulate contamination and light pollution.
4. Relatively high altitude of site (approx. 4,000 ft)
5. WSMR has extensive technical facilities which may be used to augment scientific research via SS2 and WK2.
6. As "Anchor Tenant", VG is involved closely with the development of the Spaceport and so can ensure that any specific operational requirements are taken into account.

Spaceport America's expected area of operation in relation to Restricted Airspace of White Sands Missile Range and proximate military flight areas is depicted in Figures 5 below.

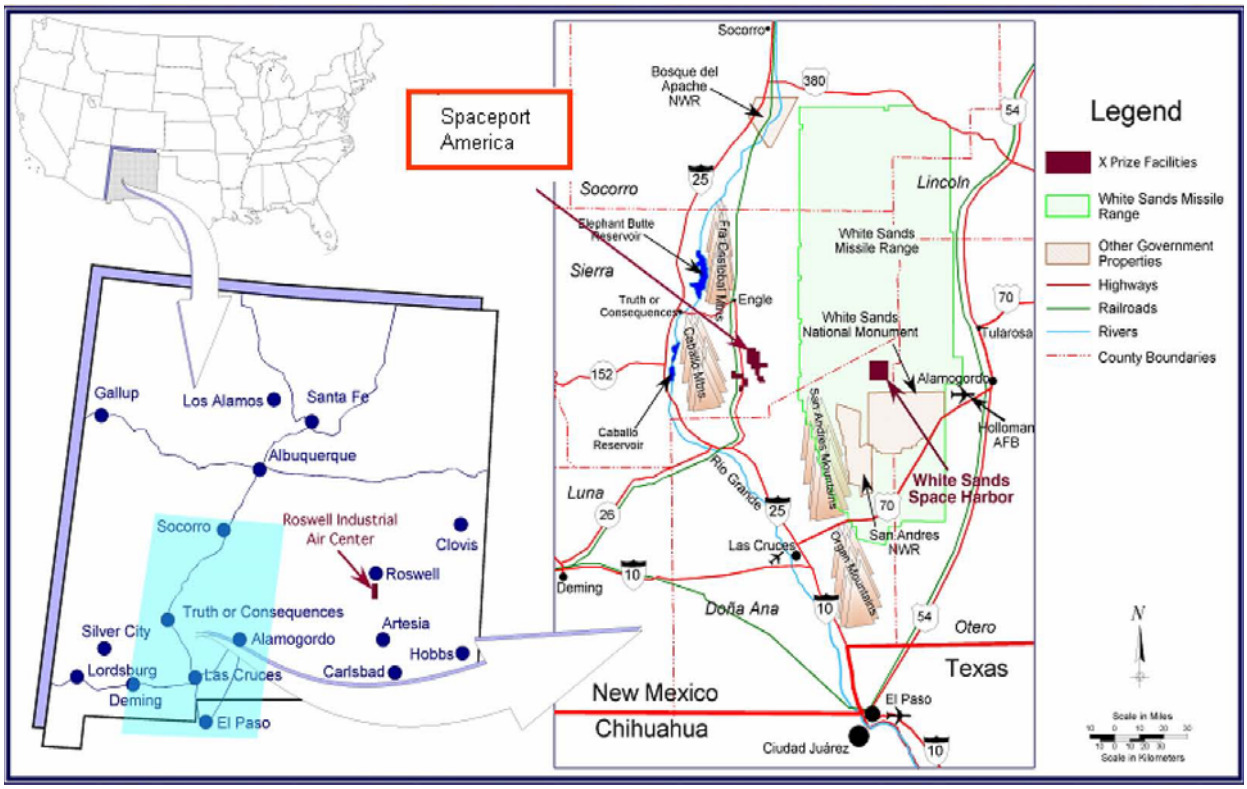

Figure 3 : Overview of Spaceport America location

With proper spaceport and commercial licensing, the SS2 / WK2 spaceflight system will be capable of operating from any typical airfield with a runway of more than 9,000ft. Specialist equipment is limited allowing operations from alternate locations with relative ease. The WK2 will be capable of ferrying an empty SS2 over 2000 nautical miles allowing access to a wide range of potential launch locations in the US.

Potential flight rates

SS2 is being designed to fly twice daily. WK2 is being designed to support four spaceflights daily. VG aims to fly 500 passengers in the first year of commercial operations and an estimated 30,000 passengers over 10 years.

During Initial commercial operations, VG is targeting a conservative flight rate of once per week rising to 3 times per week towards the end of year 1. Within two years VG expects to be flying daily and is planning to have the operational capacity to turn around multiple flights per day within three years from the start of commercial operations. Virgin Galactic hopes to eventually be able to support back to back flights with a three hour turnaround.

Conclusion

VG is moving forward quickly with the development of the SS2 / WK2 space launch system. VG's combination of assets and advantages makes it uniquely well-suited to providing a "Human in the Loop" sub-orbital science service. The company is motivated to work diligently with scientist and research agencies to bring this program into reality.